THE 2003 PARAMETRIC GRID SOFTWARE SUITE FOR GROUND-BASED NUCLEAR EXPLOSION MONITORING RESEARCH & ENGINEERING

James R. Hipp, Randall W. Simons, and Lee A. Jensen

Sandia National Laboratories

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ABSTRACT

One of most important types of data in the National Nuclear Security Administration (NNSA) Ground-Based Nuclear Explosion Monitoring Research and Engineering (GNEM R&E) Knowledge Base (KB) is Parametric Grid (PG) data. PG data can be used to improve signal detection, signal association, and event discrimination, but so far its greatest use has been for improving event location by providing ground-truth-based corrections to travel-time base models. In this presentation we will discuss the latest versions of the suite of GNEM R&E tools developed by NNSA to create, access, manage, and view PG data.

The primary PG population tool is the Knowledge Base Calibration Integration Tool (KBCIT). KBCIT is an interactive computer application whose goal is to produce interpolated calibration-based information that can be used to improve monitoring performance by improving precision of model predictions and by providing proper characterizations of uncertainty. It is used to analyze raw data and produce kriged correction surfaces that can be included in the Knowledge Base. KBCIT not only produces the surfaces but also records all steps in the analysis for later review and possible revision. New features in KBCIT include: support for 3D travel time models; auto-generation of polygon transition boundaries; enhanced decimation of complex region boundaries; and a new detailed tutorial providing step-by-step instructions for most functionality.

The Parametric Grid Library (PGL) provides the interface to access the data and models stored in a PGL file database. The PGL represents the core software library used by GNEM R&E tools that read or write PGL data (e.g., KBCIT). The PGL also provides a common access interface, the Run-Time Object Manager, for many of the United States National Data Center codes. The library provides data representations and software models to support accurate and efficient seismic phase association and event location. The PGL currently provides direct support for travel-time, slowness, azimuth, and amplitude data, as well as for generalized geophysical model data. PGL stores all of its data and model representations as Serialized Binary Stream Objects (SBSOs) that can be conveniently accessed using a set of database key objects. The key objects contain the SBSOs' descriptive meta-data information. Because PGL supports the KBCIT and Data Management Tool (DMT), some new features in those tools required corresponding modifications to PGL.

The DMT provides access to PG data for purposes of managing the organization of the generated PGL file database, or for perusing the data for visualization and informational purposes. It is written as a Graphical User Interface that can access the key file associated with any PGL file database and display it in an easily interpreted visual format. The format allows a user to view the entire object reference and dependency hierarchy, to remove objects from a database, copy objects from one database to another, or create new minimal PGL file databases that use a subset of one or more existing PGL file databases. The DMT also provides a mechanism to textually or visually display the content of any SBSO in a PGL file database. It provides a means to locate and remove redundancy and to evaluate the overall storage efficiency of each type of supported SBSO. Most of the objects supported by the PGL lend themselves to visualization. Each PGL object that can be visualized has a visualization interface that can be launched from the DMT. Some visualization interfaces have data export capabilities providing data formatted for use by other analysis tools. New features in DMT include import/export of ASCII representations of travel time, azimuth, and slowness base models (2D and 3D), as well as site information and ellipticity corrections.

OBJECTIVE

Monitoring sensor data for possible nuclear explosions involves four fundamental tasks: signal detection, signal association, event location, and event identification. For all but the first of these, the task is accomplished by minimizing the misfit between observations and theoretical predictions, which in turn are dependent on the model of the Earth used. Thus, improving the quality of the Earth model used for monitoring is of critical importance and this is why it is a primary focus of the GNEM R&E efforts.

Having a better Earth model, is not enough, however; if the model is to be maintained and used for operational monitoring, we need a cohesive set of software tools to leverage the improved model's benefits. Population tools are needed to make it easy to process the data into the proper format, and to update the model when new data becomes available. The Earth model must be designed and defined into an integrated and extensible software system. An interface is needed around the model to serve predictions to various applications. An efficient, extensible storage format is needed to archive the model on disk. Finally, some sort of data management and viewing utility is needed to easily allow users to browse through the model to better understand it, and to make simple edits (deletions, insertions) as needed.

Researchers at Sandia Labs have been working to meet these needs by developing an integrated suite of tools collectively expressed as the Parametric Grid Software Suite (PGSS).

RESEARCH ACCOMPLISHED

The PGSS consists of the primary data population tool, KBCIT, the low level storage, representation, and model library, PGL, the database management tool, DMT, and the viewing and export tool, VExTool. We briefly describe each tool below accompanied by new enhancements incorporated over the previous year. See Hipp et al. (2002) for more information concerning the basic operation of each tool.

Knowledge Base Calibration Integration Tool (KBCIT)

The Knowledge Base Calibration Integration Tool (KBCIT) is an interactive computer application whose goal is to produce interpolated calibration-based information that can be used to improve monitoring performance by improving precision of model predictions and by providing proper characterizations of uncertainty. It is used to analyze raw data and produce kriged correction surfaces that can be included in the Knowledge Base. KBCIT not only produces the surfaces, but also records all steps in the analysis for later review and possible revision.

KBCIT allows the user to define the boundaries of regions, where the data in each region can be treated differently, including using different base models, trend removals, outlier limits, and variograms in each region (See Figure 1). KBCIT allows the user to set parameters for blending functions to apply across region boundaries to avoid discontinuities. A declustering operation is available to reduce data-set size by removing redundancy, and stabilize kriging by averaging values close to one another.

KBCIT uses the Parametric Grid Library, described below, to implement both stationary and non-stationary Bayesian kriging for interpolation of empirical data with uncertainties (See Figure 2). The results of kriging can be cross-validated by comparing empirical values with interpolated predictions based on a kriged surface formed using all but the values to be compared.

To provide a faster alternative to interpolating a kriged surface, the user can specify a tessellation on which KBCIT will pre-compute kriged values. Any combination of kriged and tessellated surfaces can be summed or differenced and viewed with an interactive 3D viewer (See Figure 3). Kriged and tessellated surfaces can be saved in a Parametric Grid database for use by other programs such as those doing event location.

New features added to KBCIT this year (2003) include:

1. Azimuth and Slowness Data and Models – Added the ability to generate surfaces for azimuth and slowness observations, and created new base models to allow the computation of residuals.

2. 3D Travel-Time Models – Added support for base models with parameters (latitude, longitude, depth), allowing residuals to be computed relative to 3D models.

3. Multi-Polygon Regions – Added support for kriging regions made up of many polygons, to allow complex continental and oceanic regions.

4. Default Transition Boundaries - Added decimation of complex region boundaries, and auto-generation of transition bounds with user-specified width.

5. User-Interface Improvements – Allow selection of observations on the map to highlight corresponding rows in the observation list; zoom-in on the variogram plot and limit the portion used for auto-fit; improve default variogram values for amplitude data; load a single kriging set from a project.

6. Documentation - Added a 40-page tutorial, giving step-by-step instructions for most functions KBCIT can perform.

7. Travel-Time Tables - Updated standard IASPEI 91 and AK135 travel-time tables to match what the Air Force Technical Application Center is using in the operational system.

8. Project-Specific Configuration Files – Added the option to allow configuration for a project to override a user's configuration.

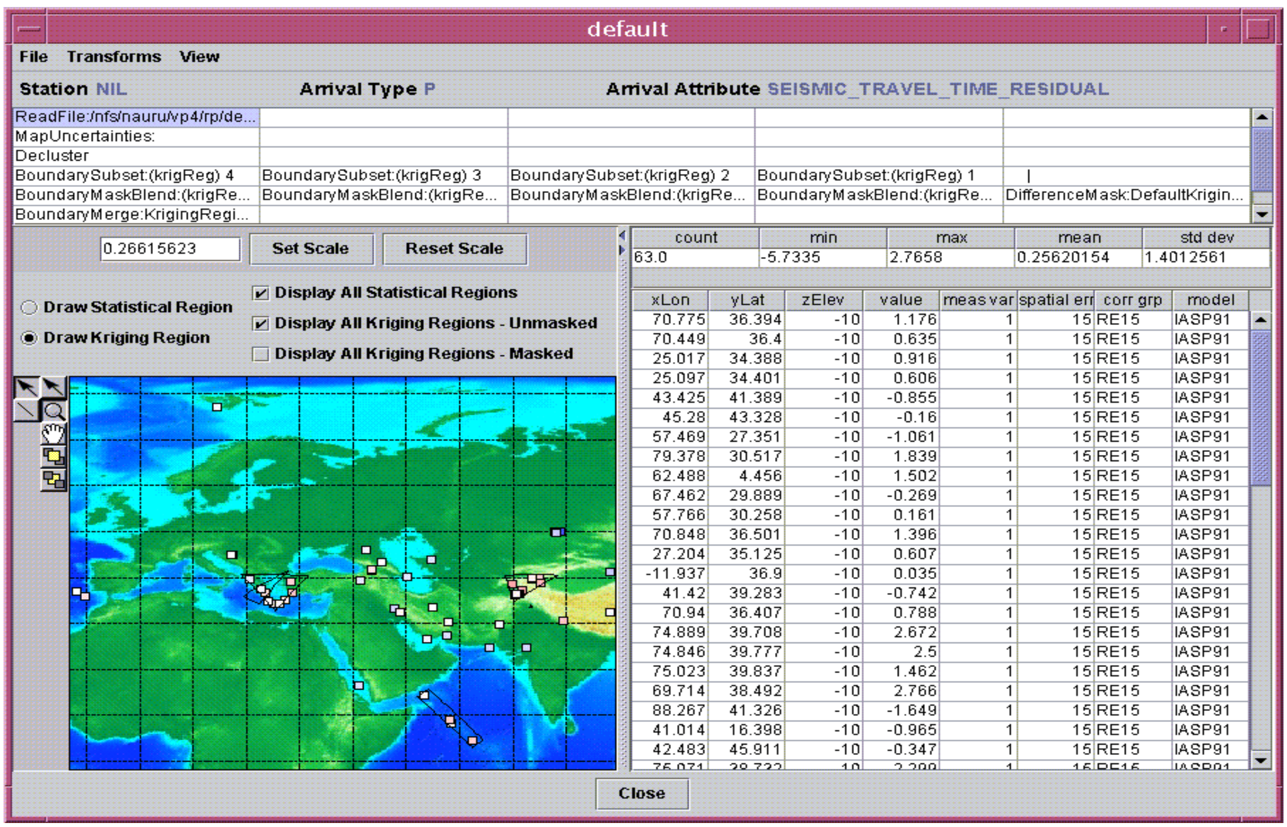

Figure 1. Kriging set window in KBCIT

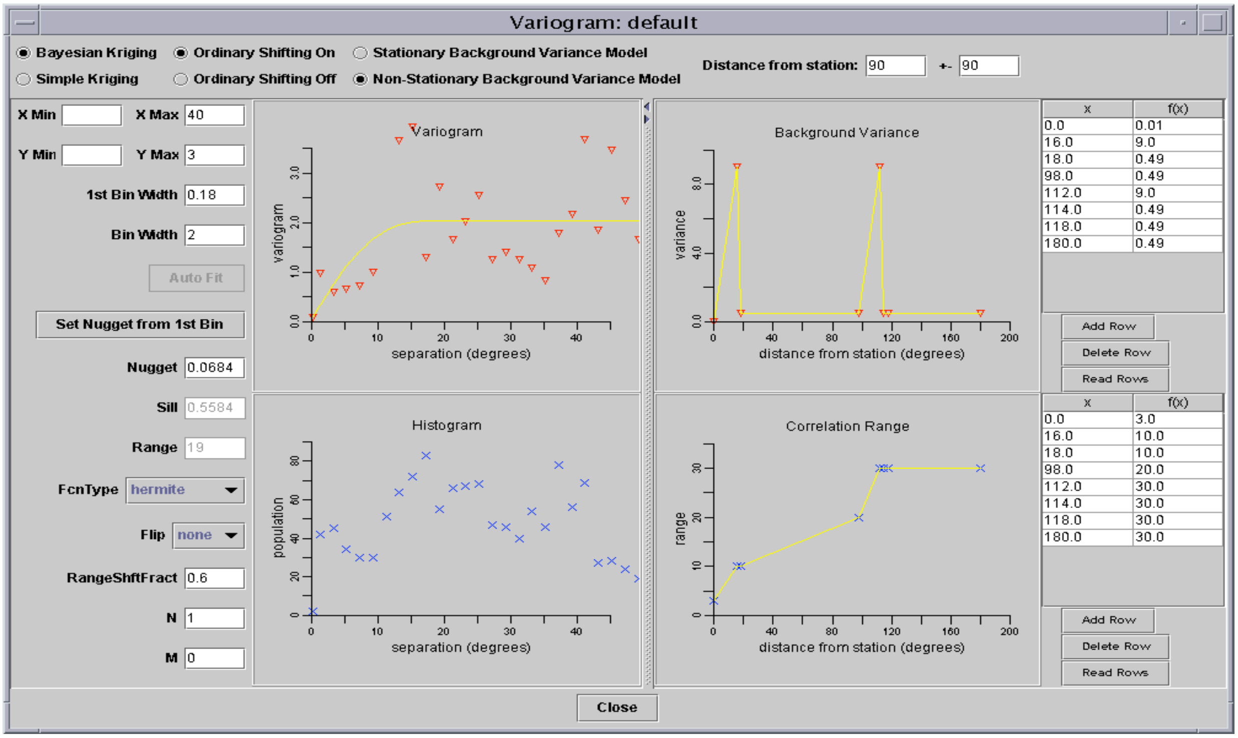

Figure 2. Variogram window in KBCIT

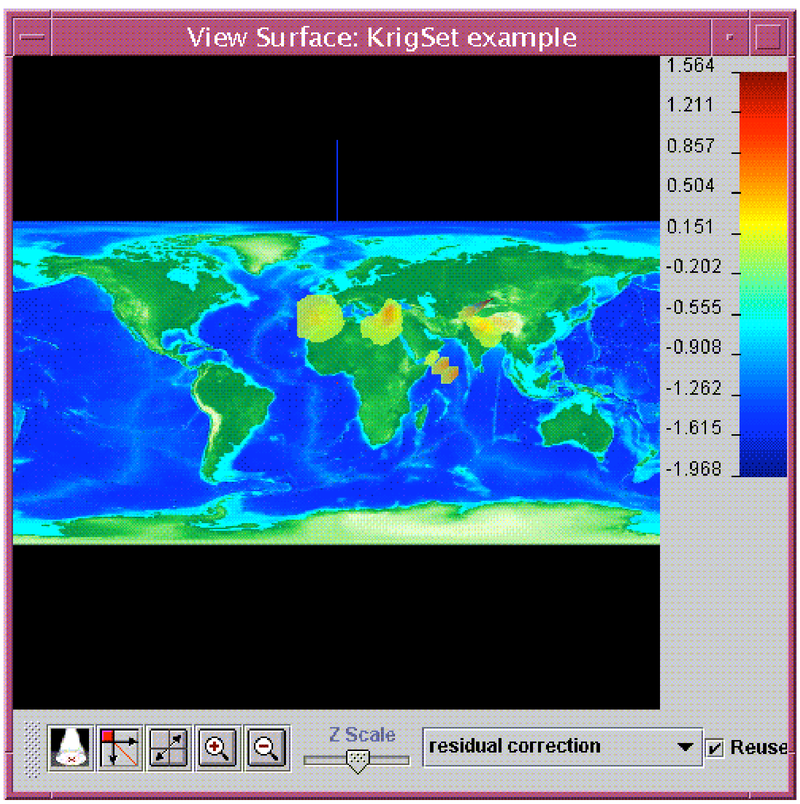

Figure 3. View surface window in KBCIT

Parametric Grid Library (PGL)

The Parametric Grid Library (PGL) provides the internal representation and client interfaces to access the data and models utilized by GNEM R&E tools. This includes tools that provide a means of populating the PGL (e.g., KBCIT described above) and those that require access to its data or models (e.g., U.S. National Data Center codes). The library can be divided into several distinct functional groups that provide necessary library capability. These groups include:

1) A physical-models group that supports basic and complex seismic modeling, Bayesian kriging for providing enhanced path corrections to the seismic models, and multi-region polygonal representations to provide a means for smoothly transitioning from discrete models defined in different tectonic regions;
2) A geometry group that provides the interface and representation functionality to support a variety of 1D, 2D, and 3D representation schemes; these include parametric and tessellated curve, surface, and volume representations, and a 2D point location facility;
3) A tessellation group that provides a means of generating and subsequently representing tessellated data for purposes of data interpolation and spatial searching;
4) A database group that defines the means to store and access arbitrary object data in a rapid manner;
5) An interfaces group that provides a Run-Time Type Identification (RTTI) facility for creating, managing, and destroying all database object types, and various client Application Programming Interfaces (APIs) for interfacing directly with the PGL functionality; and finally
6) A general utility group for providing other types of PGL requirements such as geometric vector support, memory management, and core-level base-class definitions.

Figure 4 depicts the structure of the various PGL groups outlined above.

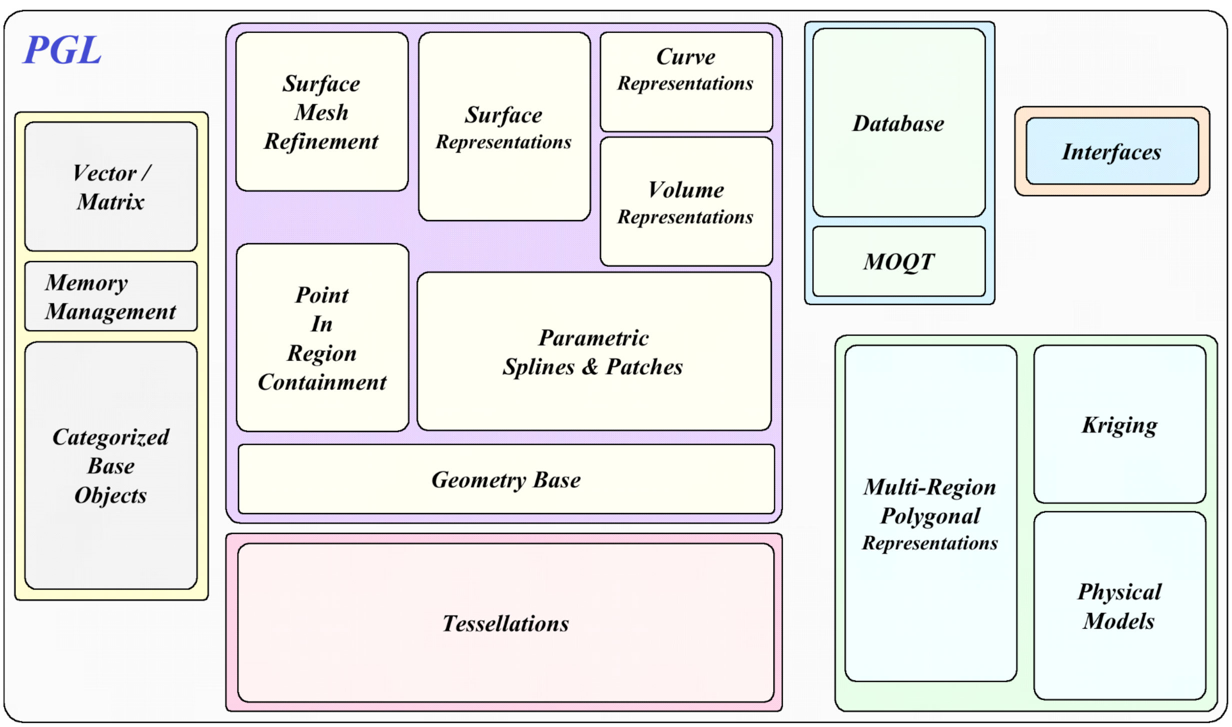

Figure 4. The six major groups of the PG software library and various subcomponents of each group

This year (2003) several new features were added to the PGL interface including:

1. Added a new exception logging service. The new service tracks all errors/warnings that occur in any function of the PGL interface and reports those messages immediately to calling clients. Additionally, clients can access the message queue programmatically or dump the queue to an ASCII file at any time during the PGL execution phase.

2. Produced a new Date/Time facility. This object was initially constructed by Sandy Ballard for the LocOO tool but was seen to have broader applicability across GNEM tools and was modified and moved to PGL in late 2002. The Date/Time object is used in PGL to set station activity and positions as a function of the stations operational history. In this way event location codes (e.g., LocOO, LocSAT, EvLoc, etc.) can set the time for which an arrival is detected at a station and guarantee that the proper historical station position coordinates are used.

3. Added a new results access interface to the PGL API. The new interface provides a common data access blueprint through which any output-centric PGL object can be mapped. This mapping simplifies results access by providing a common set of results access functionality regardless of the internal structure and implementation of the PGL object.

4. A new directory structure for seismic base-data objects and support of import/export functionality. Supported seismic base-data objects include travel-time, azimuth, slowness, and amplitude models, base models, and 3D regional model representations. The new directory structure provides for three different client initiated data access modes including accessing existing seismic base data in a default directory structure; retrieving, copying, or merging from one seismic base-data directory into another; or accessing new data that is currently not contained in any seismic base-data directory. The DM software now supports a graphical user interface (GUI) driven import/export functional interface for manipulating the new seismic base-data structure. The new interface can extract a seismic base-data directory from any PGL File Database (FDB) and write the extraction as an ASCII seismic base-data directory. Conversely, the new interface can also read an ASCII seismic base-data directory and export the entire directory as a PGL FDB.

5. Added a new crustal depth model (Laske, Masters, and Reif from Bassin et al. 2000). The crustal model is used to fade path corrections, which are developed for events occurring in the crust, to zero as the event location deepens beyond the local crustal depth. This avoids incorrectly adding path-corrections to events that are beyond the depth for which the path corrections were developed. The crustal depth is modeled as an internal parametric surface using the 2 x 2 degree spacing specified in the model. If path-corrections are present the crustal depth is interpolated from its defining parametric surface and compared to the depth at which the path correction is being requested. If the requested depth is less than the computed crustal depth the correction is returned un-altered. If the requested depth is greater than the crustal depth by some user defined fraction then zero is returned for the path correction. A smoothly varying weight (between 1 and zero) is used to multiply the path correction for requested depths that are greater than the crustal depth but less than the crustal depth plus the user-specified fraction. In this way the path correction can vary smoothly with depth, from its nominal value for event locations that are shallower than the crustal depth, to zero for requested depths that are much deeper than the crustal thickness.

In addition to the new PGL modifications mentioned above, a new PGL graphics interface is currently undergoing development using the Visualization Toolkit (VTK) software (Schroeder et al. 2003). The new interface, and its high-level Java driver and GUI, will be used to provide DMT (see below) and the new GNEM Knowledge Base Navigator tool (KB Navigator) with visualization capability for visualizing 1D, 2D, 3D, and layered volume PGL objects. This functionality is discussed in greater detail in the next section.

Data Management Tool (DMT)

The Data Management Tool (DMT) provides access to the PG data for purposes of managing the organization of the generated PG database, and for perusing the data for visualization and information purposes. The tool is written in Java providing a GUI front end and a JNI interface into PGL. The visualization component is primarily handled by the VExTool application, which is the topic of the next section.

The database management facilities of the DMT include a means for inspecting the entire object reference and dependency hierarchy for any object in multiple databases simultaneously. These facilities provide mechanisms to copy or move objects and their dependents from one database to another or to simply remove them from their containing database entirely. These services allow a user to construct new databases from existing databases that use a subset of the objects contained in any of the existing databases. This functionality provides a means for users to build databases that are tailored for spatially interesting regions or that contain objects that are specific for certain types of problems (e.g., seismic location). Figure 5, below illustrates a typical hierarchical dependency view of a database including object Meta Data Key (MDK) listings and their dependents.

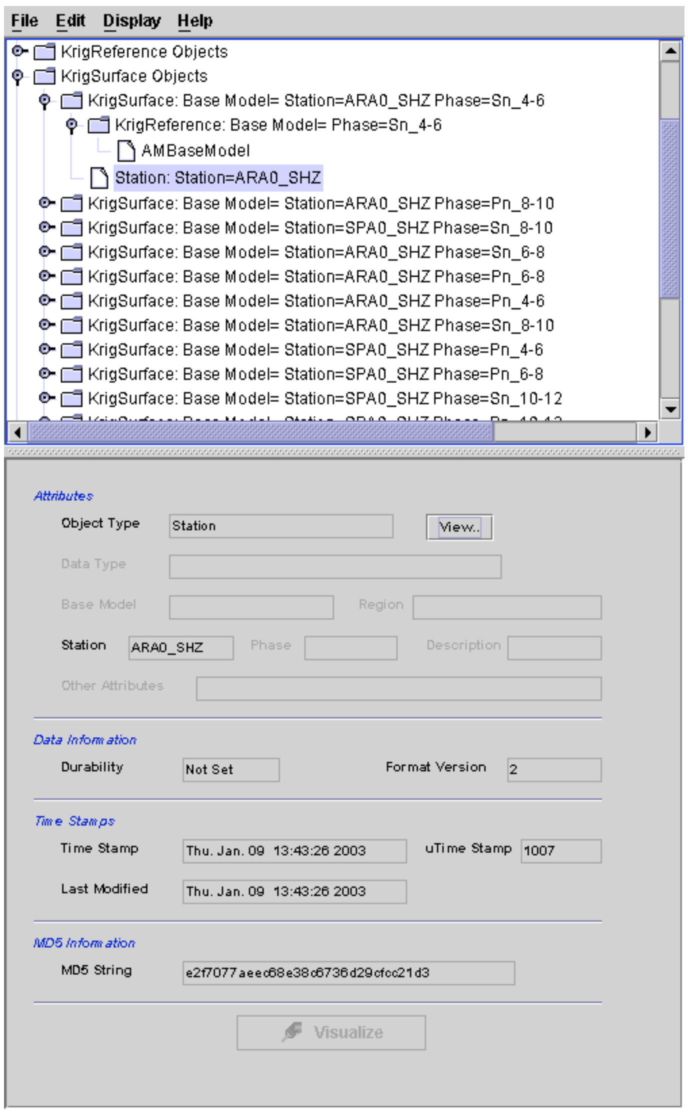

Figure 5. A typical screen shot of the DMT GUI displaying a hierarchical view of the database objects and their dependents.

In addition to database object construction, the DMT also provides services for managing MDK modifications. These services permit a database administrator to correct errors or deficiencies in an MDK object in the database. Obviously, some of the MDK data cannot be changed such as object type, location of the Serialized Binary Stream Object (SBSO) in the database, dependent object Key String Identifiers (KSIs), etc. However, attribute and descriptive data can by modified and replaced back into the database without harming the overall database structure. This service is a key feature for performing routine maintenance on existing PG databases.

Another maintenance service involves generic searching facilities. Searching allows a user to discover specific patterns of data within the database. Search requests are formulated by supplying a generic search MDK object with the attributes of interest filled with desired patterns, and unimportant or irrelevant patterns left blank. All matches are returned to the user for inspection.

Finally, the database can be inspected for duplicate binaries. These are objects that have two or more MDKs that all point to SBSOs that are duplicates of one-another. This duplication can happened when identical objects are created at different times producing new MDKs with a different KSIs. These duplicates can be discovered and all but one may be removed. The DMT automatically updates the database dependency hierarchy to reflect the changes.

Aside from these features the DMT can also load individual SBSOs for examining the contents in a textual format. This data is not available for change, as only a population tool is capable of modifying the data, but it does provide a means for a researcher or analyst to examine the defining data from which the object is composed. Also, as mentioned above, the DMT can request a visual inspection of an SBSO by calling the primary VExTool visualization service. This is described in more detail in the next section.

Viewing and Export Tool (VExTool)

The primary role of the VExTool is to visualize the properties of any geometric object in a PG database, regardless of the object's type or dimension. It is also used to export interpolated model data to a number of third-party tools utilized by GNEM researchers. The VExTool interface was written in Java and provides a user friendly GUI for manipulating complex objects graphically. The tool utilizes a JNI interface for accessing the PG data and models directly through the PGL CGI object described above.

VExTool can display an individual property of an object in 1, 2, or 3 dimensions or a range of properties as a set of curves or surfaces. Additionally, VExTool can display multiple views of the same object simultaneously. Figure 6 illustrates a typical VExTool screen dump where a property of a layered volume object is displayed simultaneously with a 2D cross-section and a 1D positional borehole.

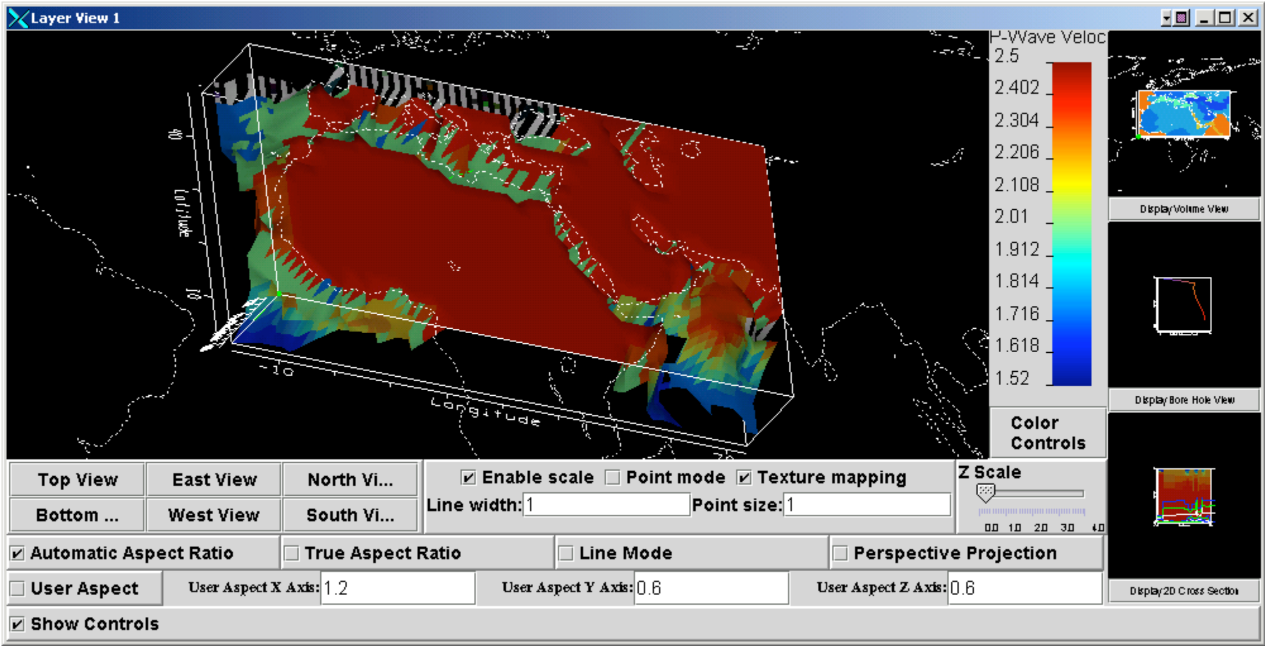

Figure 6. A typical VExTool screen shot where a 3 dimensional layered volume object is shown displaying various geophysical properties in 3D, 2D cross-section, and 1D bore hole depictions.

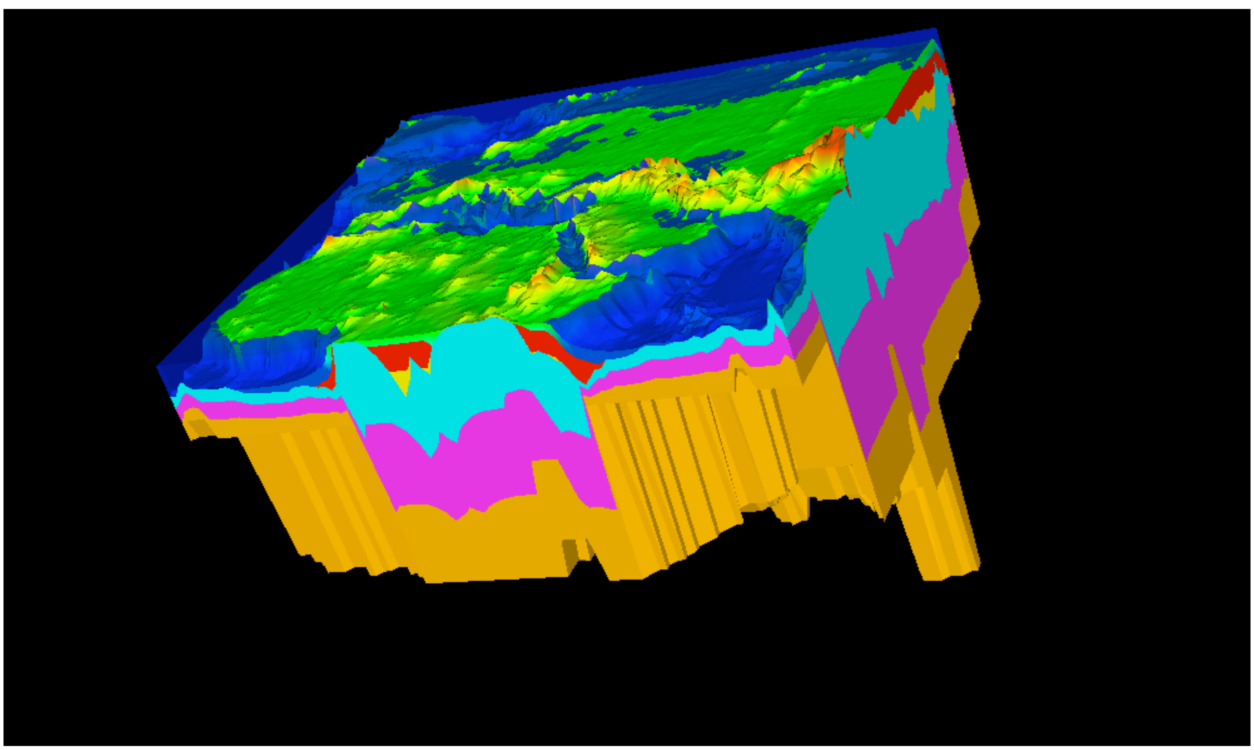

Figure 7. A screen shot of VTK graphics being incorporated into the VExTool.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, researchers at Sandia National Laboratories have described a set of integrated software tools and their associated enhancements over the past year. The tools were developed to take advantage of the improvements in the new GNEM R&E Earth model. This integrated set of software, known as the Parametric Grid Software Suite, consists of data population, storage, modeling, and data management and viewing tools.

The population tool, KBCIT, provides interpolated calibration-based information that can be used to improve monitoring performance by improving precision of model predictions and by providing proper characterizations of uncertainty. The underlying software representation of the GNEM R&E improved Earth model is provided by the PGL. The PGL also provides a generalized object database for storing model data and a set of API interfaces utilized by the population, data management, and viewing tools. The PG data-management facilities are handled by the DMT. The DMT is primarily responsible for maintaining and validating PG databases and for creating subset databases from existing ones. Finally, all model object-viewing and data-export facilities are provided by VExTool.

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